THE EFFECT OF THE MOISTURE CONTENT OF WOOD ON THE LAYER PERFORMANCE OF WATER-BORNE VARNISHES

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The test panels obtained from Scots pine (*Pinus sylvestris* L.) and Eastern beech (*Fagus orientalis* L.) were initially adjusted to have 8%, 10%, and 12% moisture content in this study. One-component semi-matte and two-component water borne varnishes were applied on the surfaces in order to investigate the effect of the type and the moisture content of the wood on the hardness and the gloss values as well as the adhesion strength of the varnishes. The hardness of the test samples was evaluated based on the standard ANS/ISO1522, the gloss based on TS.4318 EN ISO 2813, and the adhesive strength based on ASTM D-4541. The results indicated that variations in the moisture content of the wood material adversely affected the layer performance of water-borne varnishes and that the best performance was obtained for the wood with moisture contents of 8% and 10%.

Keywords: Wood material; Moisture content; Waterborne varnishes; Hardness; Gloss; Adhesion strength

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INTRODUCTION

Water, which is present in a wooden object or which may penetrate into the wood at later times, is significant in terms of the evaluation of the performance of the surface finishing that is applied on wooden furniture and on wooden decorative elements (Wheeler 1983). The moisture content of the wooden material is an important parameter in processes such as bending, drying, impregnation, and surface finishing. The hydroxyl groups in cellulose and lignin bond with the water molecules and become saturated during the humidification of wooden material (Sönmez *et al*. 2009; Kollmann and Cote 1984). The varnish layer-surface bonding cannot be effectively established on wooden surfaces with high moisture contents. As well as reducing the adhesion of the large polymer molecules, the small water molecules might also prevent the chemical bonding of the varnish with the wooden material, since they first saturate the hydroxyl groups (Sönmez and Budakçı 2004). This phenomenon is fundamental for the varnish, which is cured by polymerization. Subsequently, attained or existing moisture level plays a critical role in the success of the wood finishing processes (Wheeler 1983; De Meijer and Militz 2001; De Meijer 2002). Porosity, which is typically the void volume in the wood, ranges from 55% to 70%, depending on its specific gravity in addition to the moisture content, is a significant factor affecting the adhesion strength of the bonded samples (Zavarin 1984).

Also, the wettability and the capillarity of the surface influence the capability of the coating to have good penetration (Wicks *et al*. 1999; Allen 1987; Rijckaert *et al*. 2001; Ahola *et al*. 1999). Penetration is a function of the species, and its anatomical structure, as well as the environmental conditions, under which the process is carried out. For instance, the ratio of the latewood to the early wood is one of the important parameters affecting the penetration of a coating (Kollmann and Cote 1984).

Adequate adhesion of the varnish layer on the wood surface may not be attained if the moisture content is too high (Sönmez and Budakçı 2004). The general mechanism of adhesion between the coating and the wood surface has been considered in various studies. Typical adhesion mechanisms are chemical, mechanical, electrostatic, and acid-base adhesion (Rijckaert *et al*. 2001; De Meijer and Militz 2000; Jaic and Zivanovic 1997; Ozdemir and Hiziroglu 2007; Nelson 1995; Corcoran 1972; Mittal 1995). Adhesion strength of a coating can be determined by various methods, including the axial pull-off tests, the shear test with a torque system, the block shear test, and the semi-quantitative cut or cross hedge test (Bardage and Bjurman 1998; Williams *et al*. 1990). The first two methods are widely used for the evaluation of adhesion strength of different types of coatings (Ozdemir and Hiziroglu 2007).

In view of the literature in this field, it was determined that the difference in moisture content had substantial effect on the adhesion of varnishes applied on the wood surfaces. The strongest adhesion was obtained from the use of two-part polyurethane varnish, applied on oak specimens with a moisture content of 8% (Sönmez *et al*. 2009). The presence of excess moisture in the wood creates layer defects in polyester, polyurethane, and some other reaction curing varnishes (Sönmez 1989). In another study, various hardness and adhesion tests were carried out on wood with moisture contents of 7.3%, 10.3%, and 13% coated with a two-component polyurethane varnish surface finish. Results indicated that the highest hardness and adhesion values were achieved with the 10.3% moisture content (Jaic and Zivanovic 1997).

Yet another study reported higher values of adhesion strength on broad leaved tree woods rather than coniferous tree woods, and the highest adhesion strength was attained for polyurethane and acrylic varnishes. Additionally, it was reported that the largest failure in terms of adhesion was observed at the intersection between the filling varnish and the wooden material in the investigation of the inter-layer adhesion strength, and that the finishing varnish layers on top of the filling varnish would not affect the adhesion strength (Budakçı and Sönmez 2010). The type of wood would not influence the determination of the hardness of the finishing varnish layers on the surface of furniture manufactured from different types of trees, but the real effect was attributable to the type of varnish (Sönmez 2005). The gloss of the varnish layers was determined mainly to be dependent on the smoothness of the surface as well as its ability to reflect light, and the water borne varnishes were reported to induce the swelling of the fibers in the wooden material due to their water content, thus both adversely affecting the smoothness of the surface and reducing the gloss of the layers (Sönmez and Budakçı 2004). In a study of different types of varnishes applied on different types of wood by different methods of application, the hardness, gloss, and the adhesion strength of water borne varnishes were determined to be less than those of solvent borne vanishes. Also, the variation in the method of application would not influence the hardness and the adhesion strength of the varnish layers, although the spraying method was determined to be influencing gloss (Sönmez *et al*. 2004).

The water-based systems are becoming more broadly used with the passage of time owing to their superior characteristics as being more environmentally friendly than solvent based systems and being less harmful for their user. The use of water-based systems, which are foreseen as the paint-varnish systems of the future, was thought to be a good fit for the goals of the present study. It was aimed to determine under which conditions the water-based systems would display better layer performance and to provide support information to the executors in that respect.

EXPERIMENTAL

Materials

Wood material

The test samples were prepared from Scots pine (*Pinus sylvestris* L.) and Eastern beech (*Fagus orientalis* L.), which are widely used in the woodwork and furniture industries in Turkey. The samples were prepared as stated in TS 2470 from randomly selected 1st grade knotless and crack-free wooden material with uniform fibers of uniform color, and specific gravity with annual rings vertically positioned on the surface. The samples with a moisture content ensured by air-drying were cut into the dimension of 110x110x12mm as roughcast. Then, the samples were left in air-conditioning cabinets; at 20 ± 2ºC temperature and 42 ± 5% relative humidity for 8% moisture content, at 20 ± 2ºC temperature and 53 ± 5% relative humidity for 10% moisture content, and at 20 ± 2ºC temperature and 65 ± 5% relative humidity for 12% moisture content until their mass no longer varied. The mean moisture content of 10 randomly selected samples, from every class of moisture content, was determined as 8±0.5%, 10±0.5%, and 12±0.5%, as indicated by the principles stated in TS 2471. The roughcasts were sanded first by sandpaper with a grain size 80 and then with a grain size 100 to be prepared for varnishing after they were sized down to the net dimensions of 100x100x10 mm.

Varnishes

The one-component semi-matte (A) and two-component gloss (B) water-borne wood varnishes that are listed by their research codes in Table 1 were used in the finishing of the test samples. Information regarding several technical properties of these varnishes is given in Table 2.

Table 1. Varnishes Used in the Experimental Runs

Type of Varnish	Company Code	Research Code
One-component water-borne (semi-matte)	Tri-metal	A
Two-component water-borne (glossy) (two-pack catalyzed)	AST D 17 Primer	B_1
	AST D 18 Filling	B_2
	AST D 45 Topcoat	B_3
	AST D 45 Improver	B_4

Table 2. Characteristics of the Varnishes Used in the Study

Type of Varnish	pH	Density g/m^3	Application Viscosity (second /DIN Cup 4mm/20 °C)	Amount of Varnish Applied (g/m^2)	Solid Content (%)
A	8.8	1.03	18	70	33.60
B_1	9.2	1.15	18	100	14.20
B_2	8.2	1.25	18	67	40.80
B_3	8.6	1.25	18	67	35.20

The ASTM D-3023 principles and the suggestions by the production companies were followed in the application of the varnishes. The amount of varnish was determined on an analytical balance with ± 0.01g sensitivity, and it was uniformly applied by a medium-hardness bristle brush.

The varnish A was applied in three consecutive coats with 24 hr intervals, without any sanding in between layer applications. During the application of the varnish B, a single coat of B_1 was applied in order to prevent unnecessary absorption of the varnish and to increase the layer performance; 2 coats of B_2 were applied on top with 1 hr intervals in between. The samples were sanded using 180 sandpaper after 24 hours. Then B_4 mixed with B_3 was applied for 3 coats with 1 hr intervals as indicated by the company's instructions.

Methods

Measurement of adhesion

Varnished and dried samples were conditioned at a temperature of 23 ± 2 ^{o}C and a relative humidity of 50 ± 5 % for a period of 16 hours as stated in ASTM D-3924. Stainless steel test cylinders (20 mm in diameter) were attached to the conditioned surfaces at ambient temperature (20 °C) to perform a pull-out test as outlined in the standard. A double component high strength epoxy with no dissolving effect on varnish layers was used at a concentration of 150±10 g/m^2 as specified in ASTM D-4541. The adhesion strength of the varnish layers was determined with a standard adhesion device (Budakçı 2006).

The adhesion (X) was calculated in terms of MPa using Eq. 1,

$$X= 4F / \pi .\ d^2 \tag{1}$$

where F is the rupture force (Newton), and d is the diameter of the experiment cylinder (mm) (ASTM D-4541 1995).

Measurement of hardness

The dried samples were conditioned at a temperature of 23 ± 2 ^{o}C and a relative humidity of 50 ± 5% for a period of 16 hours in a conditioning cabinet. This was done prior to the hardness measurements that were carried out by the pendulum hardness tester that uses the Köning method as stated in the ANS/ISO 1522 principles.

The test device determines the hardness of the layers based on the undulation of the pendulum consisting of two beads, each with a diameter of 5±0.0005 mm and a hardness value of 63±3.3 HRC on the sample surface that was placed on the sample platform (Sönmez 1989).

Measurement of gloss

The test samples that were completely dried, following the application of the varnish, were first conditioned at a temperature of 23 ± 2 ^{o}C and a relative humidity of 50 ± 5 % for a period of 16 hours in a conditioning cabinet, and then the gloss measurements were made using a gloss meter as stated in TS 4318 EN ISO. The values that were obtained by testing the samples at a reflection angle of 60°±2° were evaluated in comparison to the black calibration glass panel with a gloss degree of 100.

A reflection angle of 20° is used to determine the gloss of the matte layers, 60° is used to determine both matte and glossy layers, and 85° is mostly used to determine very glossy layers in the identification of the gloss of the paint and varnish coating finishes (Sönmez 1989).

Each surface was measured in two different orientations, one of which was perpendicular to the fibers and the other in parallel with the fibers. The arithmetic mean of the values was taken into consideration in terms of the resulting measurement. The statistical evaluation was conducted for varnish A and varnish B separately (varnish A = semi-matte, varnish B = glossy).

Statistical evaluation

A statistical software package called MSTATC was used in the statistical evaluation of the data. In the analysis, the values of the factor effects based on the wood type, varnish type, and the moisture content were determined through multiple variance analysis, ANOVA, and in cases where the factor effects were significant at a level of α= 0.05. The error rate based on this variance analysis was determined through the Least Significant Difference (LSD) critical values and the error inducing factors were determined.

RESULTS AND DISCUSSION

Evaluation of the Adhesion Measurements

The results of the multiple variance analysis on the surface adhesion strength of the water borne varnishes that were applied on the surfaces of different types of wood material at varying moisture contents are displayed in Table 3.

The results of the analysis of variance indicated that the adhesion strength was statistically significant in terms of the type of varnish and statistically insignificant or meaningless in terms of other factors and their interactions (α=0.05).

Based on this outcome, the results of the comparison of the values based on the conducted Duncan test, in which the LSD critical values at different levels of varnish type were used, are given in Table 4.

Table 3. Results of Multiple Variance Analysis in Terms of Surface Adhesion Strength

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Level of Significance (P<0.05)
Wood Type (A)	1	0.190	0.190	1.0743	0.3052
Varnish Type (B)	1	4.25	4.025	22.8070	0.0000*
Interaction (AB)	1	0.19	0.119	0.6757	ns
Moisture Content (C)	2	0.54	0.127	0.202	ns
Interaction (AC)	2	0.65	0.233	1.184	0.2771
Interaction (BC)	2	0.14	0.207	1.732	0.3181
Interaction (ABC)	2	0.10	0.005	0.279	ns
Error	48	8.72	0.176		
Total	59	13.950			

*: significant at 95% confidence level   ns: insignificant

Table 4. Results of Singly Carried Out Comparisons for Each Varnish Type

Varnish Type	$\bar{x}$	HG	LSD± 0.2167
A Varnish	3.167	a*	
B Varnish	2.649	b	

*: The highest adhesion value. $\bar{x}$: Average value.   HG: Homogeneous group.

The highest surface adhesion strength was obtained for varnish A, and the lowest strength was obtained for varnish B based the results given in Table 4. The high values obtained for varnish A in comparison to varnish B might have resulted from its high penetration into the wood, since it has been used both as the filling coat and the finishing coat (Kollmann and Cote 1984; Zavarin 1984; Wicks *et al*. 1999; Allen 1987; Rijckaert *et al*. 2001; Ahola *et al*. 1999).

Evaluation of the Hardness Measurements

The results of the multiple variance analysis on the hardness of the water-borne varnishes that were applied on the surfaces of different types of wooden material at varying moisture contents are displayed in Table 5.

Table 5. Results of the Multiple Variance Analysis in Terms of Hardness

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Level of Significance (P<0.05)
Wood Type A)	1	822.044	822.044	72.3206	0.0000*
Varnish Type (B)	2	3033.622	1516.811	133.4438	0.0000*
Interaction (AB)	2	142.156	71.078	6.2532	0.0031*
Moisture Content (C)	2	133.756	66.878	5.8837	0.0043*
Interaction (AC)	2	0.298	0.144	0.0127	ns
Interaction (BC)	4	257.578	64.394	5.6652	0.0005*
Interaction (ABC)	4	31.311	7.828	0.6887	ns
Error	72	818.400	11.367		
Total	89	5239.156			

*: significant at 95% confidence level   ns: insignificant

All factors and interactions except for AC and ABC were found to be statistically significant (α=0.05) based on these results. The comparative results of the single comparison analysis results of the Duncan test, in which the critical LSD values at the levels of wood types, varnish types, and moisture content were used, are given in Table 6.

Table 6. Results of Singly Carried Out Comparisons for Each Varnish Type, Wood Type, and Moisture Content

Wood Type	$\bar{x}$	HG	LSD± 1.412
Scots Pine	26.16	b	
Eastern Beech	32.20	a*	
Varnish Type	$\bar{x}$	HG	LSD± 1.730
Control	36.70	a*	
A Varnish	28.27	b	
B Varnish	22.57	c	
Moisture Content (%)	$\bar{x}$	HG	LSD± 1.730
8	30.83	a*	
10	28.77	b	
12	27.93	b	

*: The highest hardness value. $\bar{x}$: Average value. HG: Homogeneous group

The highest hardness values, in terms of the type of wood, were determined in Eastern beech and the lowest in the Scots pine. In terms of the type of varnish, the highest value was determined for the control (uncoated) samples, and the lowest value was determined for the samples on which varnish B was applied, as shown in the compare-sons. In terms of the moisture content, the highest hardness value was obtained for the samples with 8% moisture content, and a statistical significance could not be observed between the samples with 10% and 12% moisture content. This situation might have resulted from the fact that Eastern beech wood has a higher specific gravity than the Scots pine, thus possessing a stronger texture (Kollmann and Cote 1984). The fact that varnish A (semi-matte) provides higher hardness values than varnish B (glossy) was thought to stem from the additive agents in varnish A to synthetically impart a matt quality to the varnish (Sönmez and Budakçı 2004; Tunçgenç 2004).

The results of the comparison of the values based on the conducted Duncan test, in which the LSD critical values at the level of wood type-varnish type interaction were used, were given in Table 7.

Table 7. Bilateral Comparison Results for Wood Type-Varnish Type Interaction

Varnish Type	Wood Type			
	Scots Pine		Eastern Beech	
	$\bar{x}$	HG	$\bar{x}$	HG
Control	32.07	b	41.33	a*
A Varnish	25.40	c	31.13	b
B Varnish	21.00	d	24.13	c
LSD± 2.446				

*: The highest hardness value. $\bar{x}$: Average value. HG: Homogeneous group.

The highest hardness value was obtained for the control (uncoated) Eastern beech samples and the lowest value was obtained for the Scots pine samples, on which varnish B was applied, as indicated in Table 7.

The results of the comparison of the values based on the conducted Duncan test, in which the LSD critical values at the level of varnish type-moisture content interaction were used, are given in Table 8.

Table 8. Bilateral Comparison Results for Varnish Type-Moisture Content Interaction

Varnish Type	Moisture Content (%)					
	8		10		12	
	$\bar{x}$	HG	$\bar{x}$	HG	$\bar{x}$	HG
Control	36.70	a*	37.70	a*	35.70	ab
A Varnish	33.20	b	26.30	c	25.30	cd
B Varnish	22.60	de	22.30	e	22.80	de
LSD± 2.996						

*: The highest hardness value. $\bar{x}$: Average value. HG: Homogeneous group.

The highest value of hardness was obtained for the uncoated samples having 8% or 10% moisture content, and the lowest value was obtained for the sample with 10% moisture content, on which varnish B was applied, in the comparative analysis.

Evaluation of the Gloss Measurements

Gloss in varnish A

The results of the multiple variance analysis on the gloss of the water borne varnish A that was applied on the surfaces of different types of wooden material at varying moisture contents are displayed in Table 9.

Table 9. Results of the Multiple Variance Analysis in Terms of Gloss

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Level of Significance (P<0.05)
Wood Type (A)	1	103.788	103.788	16.180	0.0005*
Moisture Content (B)	2	3303.517	1651.758	257.510	0.0000*
Interaction (AB)	2	100.646	50.323	7.845	0.0024*
Error	24	153.944	6.414		
Total	29	3661.895			

*: significant at 95% confidence level

All factors and the interactions among them were determined to be statistically significant as a result of the analysis of variance (α=0.05). Then the comparative results of the individual comparison analysis results from the Duncan test, in which the critical LSD values at the levels of wood type and moisture content were used, are given in Table 10. The increase in moisture content was thought to result in an increase in the gloss values based on the presented in Table 10.

Table 10. Results of Singly Carried Out Comparisons for Each Wood Type and Moisture Content

Wood Type	$\bar{x}$	HG	LSD± 1.891
Scots Pine	60.61	a*	
Eastern Beech	56.89	b	
Moisture Content (%)	$\bar{x}$	HG	LSD± 2.316
8	45.77	c	
10	59.02	b	
12	71.47	a*	

*: The highest gloss value. $\bar{x}$: Average value. HG: Homogeneous group.

In terms of the wood type level, the highest amount of gloss was obtained for the Scots pine and the lowest value for the Eastern beech, whereas in terms of the moisture content level, the highest value was obtained for the samples with 12% moisture content and the lowest value was obtained for the samples with 8% moisture content. This situation might have resulted from the lighter color of the Scots pine thus reflecting the light better. Higher gloss values have also been reported for the Scots pine than for the Eastern beech in literature (Wheeler 1983; Sönmez 2005; Sönmez *et al*. 2004).

The results of the comparison of the values obtained from the conducted Duncan test, in which the LSD critical values at the level of wood type-moisture content interaction were used, are given in Table 11.

Table 11. Bilateral Comparison Results for Wood Type-Moisture Content Interaction

Moisture Content (%)	Wood Type			
	Scots Pine		Eastern Beech	
	$\bar{x}$	HG	$\bar{x}$	HG
8	46.14	d	45.40	d
10	63.46	b	54.58	c
12	72.24	a*	70.70	a*
LSD± 3.276				

*: The highest gloss value. $\bar{x}$: Average value. HG: Homogeneous group.

Based on these results, the highest gloss value was obtained for the Scots pine and the Eastern beech samples with 12% moisture content, and the lowest gloss values were obtained for the Scots pine and the Eastern beech samples with 8% moisture content.

Gloss in varnish B

The results of the multiple variance analysis on the gloss of the water borne varnish B that was applied on the surfaces of different types of wooden material at varying moisture contents are displayed in Table 12.

The factors of wood type and moisture content factors were determined to be significant as a result of the analysis of variance, whereas the interaction of these factors (AB) was determined to be insignificant (α=0.05). Then the comparative results of the Duncan test, in which the critical LSD values at the levels of wood type and moisture content were used, are given in Table 13.

Table 12. Results of the Multiple Variance Analysis in Terms of Gloss

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Level of Significance (P<0.05)
Wood Type (A)	1	15.987	15.987	4.5144	0.0441*
Moisture Content (B)	2	40.331	20.165	5.6943	0.0095*
Interaction (AB)	2	20.904	10.452	2.9514	0.0714
Error	24	84.992	3.541		
Total	29	162.214			

*: significant at 95% confidence level

Table 13. Results of Singly Carried out Comparisons for Each Wood Type and Moisture Content

Wood Type	$\bar{x}$	HG	
Scots Pine	86.47	a*	LSD± 1.405
Eastern Beech	85.01	b	
Moisture Content (%)	$\bar{x}$	HG	
8	86.13	a*	LSD± 1.721
10	86.93	a*	
12	84.17	b	

*: The highest gloss value. $\bar{x}$: Average value. HG: Homogeneous group.

The highest gloss value was obtained for the Scots pine samples in terms of the wood type level, as indicated by Table 13. A difference in gloss values could not be observed between the samples having 8% moisture content and 10% moisture content, although the lowest gloss values were observed for the samples with 12% moisture content. Based on this situation, it can be concluded that the increase in moisture content of the wooden material caused a decrease in the gloss values of the varnish B coat.

CONCLUSIONS

The results of the study indicate that the type of wood and the moisture content did not influence the adhesion strength of varnishes A and B, but the actual effect was resulting from the type of varnish that was applied.

In terms of hardness, the type of wood and varnish as well as the moisture content were all determined to be affecting the hardness value. The hardness value of the samples was found to decrease upon the application of varnishes A or B in comparison to the control (uncoated) samples, and the increased moisture content of the wood would lower the hardness value for varnish A, whereas it would not affect the hardness value of varnish B significantly.

Investigation of the gloss results indicate that the type of wood and the moisture content would affected gloss upon the application of varnish A, and the gloss value was observed to increase with increasing moisture content. On the other hand, an increase in moisture content was observed to decrease the gloss value in response to the application of varnish B.

It can be suggested that in applications that require high values of hardness, the use of Eastern beech rather than Scots pine, the restriction of the moisture content below 8%, and the selection of varnish A would be a suitable choice. In applications that require high values of gloss, the moisture content of Scots pine and Eastern beech needed to be 12% for varnish A (semi-matte), and the moisture content of Scots pine needed to be lower than 8-10% for varnish B (glossy); in applications that require high surface adhesion, the selection of varnish A would be more suitable.

REFERENCES CITED

Ahola, P., Derbyshire, H., Hora, G., and De Meijer, M. (1999). "Water protection of wooden joinery painted with low organic solvent content paints with known composition," *Holz als Roh-und Werkstoff* 57, 45-50.

Allen, K. W. (1987). "A review of contemporary views of theories of adhesion," *The Journal of Adhesion* 21(3-4), 261-277.

ANS/ISO1522 (1998). "Paints and Varnishes—Pendulum Damping Test Approved as an American National Standard by ASTM International."

ASTM D 3023 (1998). "Standard Practice for Determination of Resistance of Factory Applied Coatings on Wood Products of Stain and Reagents."

ASTM D 3924 (1996). "Standard Specification for Standard Environment in Conditioning and Testing Stain Varnish. Lacquer and Related Materials."

ASTM D 4541 (1995). "Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers."

Bardage, S. L., and Bjurman, J. (1998). "Adhesion of waterborne paints to wood," *Journal of Coatings Technology* 70(3), 39-47.

Budakçı, M. (2006). "The design and the production of a pneumatic adhesion tester," *Gazi University, Faculty of Technical Education Polytechnical Journal*, 9(1), 53-58.

Budakçı, M., and Sönmez, A. (2010). "Determination of adhesion strength of various wood varnishes on different wooden material surfaces," *Gazi University, Journal of the Faculty of Engineering and Architecture* 25(1), 111-118.

Corcoran, E. M. (1972). "Adhesion, Chapter 5.3," *Painting Testing Manual*, ASTM Special Technical Publication, Philadelphia, PA., 314-332.

De Meijer, M. (2002). "Comparison between laboratory water permeability tests and wood moisture content of full-scale window frames," *Surface Coatings International Part B: Coatings Transactions* 85(2), 131-137.

De Meijer, M., and Militz, H. (2000). "Wet adhesion of low-VOC coatings on wood. A quantitative analysis," *Progress in Organic Coatings* 38, 223-240.

De Meijer, M., and Militz, H. (2001). "Moisture transport in coated wood. Part 2: Influence of coating type, film thickness, wood species, temperature and moisture gradient on kinetics of sorption and dimensional change," *Holz als Roh-und Werkstoff* 58, 467-475.

Jaic, M., and Zivanovic, R. (1997). "The influence of the ratio of the polyurethane coating components on the quality of finished wood surface," *Holz als Roh-und Werkstoff* 55, 319-322.

Kollmann, F. P., and Côté, W. F. (1984). *Solid Wood, Principles of Wood Science and Technology*, Reprint Springer-Verlag, Tokyo, 1, 180.
Mittal, K. L. (1995). "Commentary, Adhesion measurement of films and coatings," *VSP*, Utrecht, The Netherlands, 1-13.
Nelson, G. L. (1995), "Adhesion, Chapter 44," *Paint and Coating Testing Manual*, *ASTM* Special Technical Publication, Philadelphia, PA., 513-523.
Ozdemir, T., and Hiziroglu, S. (2007). "Evaluation of surface quality and adhesion strengthof treated solid wood," *Journal of Materials Processing Technology*, 186, 311-314.
Rijckaert, V., Stevens, M., and Acker, J. V. (2001). "Effect of some formulation parameters on the penetration and adhesion of water-borne primers into wood," *Holz als Roh-und Werkstoff* 59, 344-350.
Sönmez, A. (1989). "Durability of varnishes used on surfaces of wood furniture against important physical, mechanical, and chemical effects," Ph.D. diss., *Gazi University, Institute of Science,* Ankara.
Sönmez, A. (2005). "Preparation and coloring, finishing on woodworking I," *Gazi University, Technical Education Faculty*, Ankara, 3-26.
Sönmez, A., and Budakçı, M. (2004). "Protective layers and paint/varnish systems, finishing on woodworking II," Gazi University, Technical Education Faculty, Ankara.
Sönmez, A., Budakçı, M., and Bayram, M. (2009). "Effect of wood moisture content on adhesion of varnish coatings," *Scientific Research and Essay* 4(12), 1432-1437.
Sönmez, A., Budakçı, M., and Yakın, M. (2004). "Effect of water borne varnish applications on wooden material on hardness, gloss and surface adhesion," *Gazi University, Faculty of Technical Education Polytechnical Journal* 7(3), 229-235.
TS 2470 (1976). "Wood - Sampling methods and general requirements for physical and mechanical tests," *Turkish Institute of Standards*, (in Turkish).
TS 2471 (1976). "Wood - Determination of moisture content for physical and mechanical tests," *Turkish Institute of Standards*, (in Turkish).
TS 4318 EN ISO 2813 (2002). "Paints and varnishes – Determination of gloss at angles of 20^o, 60^o and 85^o for non-metallic paint films," *Turkish Institute of Standards*, (in Turkish).
Tuncgenc, M. (2004). "*General Information on Paint*, Section 6- An overall view of the raw material groups that constitute organic coatings," Akzo Nobel Kemipol Corp.
Wicks, Z. W., Jones, F. N., and Pappas, S. P. (1999). *Organic Coatings Science and Technology*, SPE Monograph Series, 2nd Ed., Wiley Interscience, New York.
Wheeler, E. A. (1983). "Wood structure and properties," *Finishing Eastern Hardwoods,* Proceedings 7318, Carter, R. M. (ed.), Forest Products Res. Soc., Madison, 5-14.
Williams, R. S, Plantinga, P. L, and Feist, W. C. (1990). "Photodegradation of wood affects paint adhesion," *Forest Product Journal* 40(1), 45-49.
Zavarin, E. (1984). "Activation of wood surface and non-conventional bonding," In: R. Rowell (Ed.), *The Chemistry of Solid Wood*, ACS, Washington.

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